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Fresh air pre-cooling and energy recovery by using indirect evaporative cooling in hot and humid region – a case study in Hong Kong

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Abstract

Evaporative cooling (EC) is an energy efficient and environmental friendly technology which uses water evaporation to absorb the heat from surroundings and produce cooling air. EC has limited application cases in hot and humid regions because of the relatively low cooling capacity. In recent years, the study on hybrid EC and traditional mechanical cooling becomes the trend to break the region limitation of the technology. This paper carries out a case study for applying the Regenerative Indirect Evaporative Cooling System (RIECS) to an all-fresh-air hybrid air-conditioning system of a wet market in Hong Kong. The condense water from an air-handling unit (AHU) is collected and used as cooling medium sprayed onto the heat exchanger of an IEC equipment. At the same time, the contaminative and exhausted air from the wet market returns to the IEC equipment to cool the intake fresh air, so that the fresh air pre-cooling before it enters to the AHUs is realized. The energy saving and economic efficiency were analyzed and compared among RIECS, rotating heat recovery wheel system and the A/C system without heat recovery. The results show that RIEC system has the largest annual energy saving potential with a payback period of 2.9 years, which shows a great potential of its application in Hong Kong.

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Keywords: evaporative cooling; fresh air pre-cooling; hot and humid regions; energy and economic analysis

1. Introduction

The Evaporative Cooling (EC) has become a research hot spot in the increasingly serious circumstance of energy shortage and environmental pollution worldwide for its better energy efficiency and environmental friendly performance. The thermal performances of the EC applied in hot and arid regions have been studied by many experts and proved to be high energy efficient, but there's limited application

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in hot and humid regions because of its relatively low cooling capacity [1]. Many researchers suggest that EC can be used as an effective way for fresh air pre-cooling combined with mechanical cooling, especially when huge amount of fresh air is needed, but the application cases are very limited [2~3].

This paper reports a case study for applying a hybrid Regenerative Indirect Evaporative Cooling System (RIECS) with mechanical cooling to an all-fresh-air A/C system of a wet market in Hong Kong. The original proposed Rotating Heat Recovery Wheel (RHRW) is substituted by the RIECS. The feasibility study has been carried out to analyse the energy saving and economic efficiency of the RIECS, and compare its performance with a wheel heat recovery system and a system without any heat recovery device. The results provide references for EC fresh air pre-cooling applications in hot and humid regions.

2. The Case

2.1. The wet market

The wet market, which sells fish, meat and chicken together with vegetables, locates in Tung Chung area in Hong Kong. As the fresh food sold in the wet trade stall will distribute smelling and moisture, the cooled air from central air-conditioning can't be reused and circulated, so all fresh air AC system is adopted for the wet trade stall. The case study focuses on the 100% fresh air system in the wet trade stall.

2.2. Air-conditional system

The A/C schematic diagram in the wet market is shown as Figure 1(a). According to the design, there are two air handling units (AHUs) installed for the wet trade area and each one is responsible for half of the area. In the original design, two rotating heat recovery wheel systems will be installed before each AHU to pre-cooling/pre-heating fresh air by recovering cold/heat from exhaust air in summer/winter.

Now, the two heat recovery wheels are proposed to be substituted by the Regenerative Indirect Evaporative Cooling System (RIECS), which is shown in Figure 1(b). In summer, the condense water from an air-handling unit (AHU) is collected and used as cooling medium sprayed onto the heat exchanger of the IEC. At the same time, the exhausted air from the wet market returns to the IEC equipment to cool the intake fresh air, so that the fresh air is pre-cooled before it enters to the AHUs.

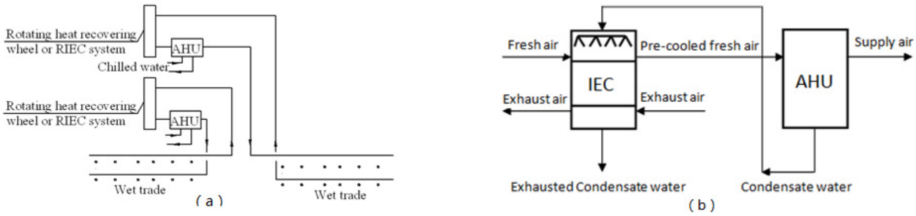

Fig.1. (a) Schematic diagram of the original A/C system; (b) Design diagram of the proposed RIECS

Two innovation points exist in the RIEC system: (1) Lower temperature and humidity return air is used as working air; (2) Condensate water is collected as the evaporative medium, which recovery the heat from the exhaust air and solve the problem of bacterial growth due to the condense water accumulation.

3. Method

3.1. Energy performance analysis

3.1.1. RIEC system

The calculation parameters are listed in Table 1. The specified exhaust air volume (5652m^3/h/AHU) is larger than that of fresh air (5112m^3/h/AHU), which can keep a negative pressure in the market and prevent the contaminated air from spreading into the surroundings. An RIEC device from ZhongHui is selected and the type is ERV-60W.

Table 1 Designed calculation parameters

No.	Season	Item	Unit	Value
1	Summer condition	outdoor design temperature（DB)	°C	32.4
2		outdoor design temperature（WB)	°C	27.3
3		indoor design temperature（DB)	°C	24
4		indoor design RH	%	60
5		supply air temperature (DB)	°C	14
6		supply air humidity	g/kg	9.9
7	Winter condition	outdoor design temperature (DB)	°C	8
8		indoor design temperature（DB)	°C	18
9	Equipment parameter	sensible heat efficiency (summer)	%	120
10		total heat efficiency (summer)	%	80
11		sensible heat efficiency (winter)	%	81

1) Summer condition

The condense water from the AHU will be collected and sprayed on the exhaust air in the IEC heat exchanger. The amount of condense water can be calculated as follows.

$$m_c = 0.001\times(d_o - d_s)\times\rho\times\frac{V_s}{3600} \tag{1}$$

Where, m_c is the amount of condense water, kg/s; d_o is the humidity of outdoor air, g/kg; d_s is the humidity of supply air, g/kg; ρ is the density of air, kg/ m^3; V_s is the supply air flow rate, m^3/h.

The temperature of the leaving fresh air is given as (2). The enthalpy of the outlet fresh air can be calculated similarity as (2) by replacing *t and* ε_s with *h,* and ε_h .

$$t_2 = t_1 - \varepsilon_s\times V_{\min}\times(t_1 - t_3)/(V_s\times 100) \tag{2}$$

Where t_1 , t_2 and t_3 are the dry-bulb temperatures of the inlet fresh air, outlet fresh air and inlet exhaust air, °C; ε_s is sensible heat efficiency, %; V_s and $V_{\min}$ are the flow rate of fresh air and the minimum flow rate of fresh and exhaust air, m^3/h.

The energy saving in summer can be divided into two parts: the heat recovered from evaporation of condensate water (Q_1) and heat exchange (Q_2). The heat recovered from evaporation is given as follows:

$$Q_1 = \gamma\times m_c\times\alpha \tag{3}$$

Where, γ is the latent evaporation heat of water, kJ/kg; m_c is the amount of condense water, kg/s and α is the evaporation coefficient, 0.5 here.

The heat recovered from heat exchange Q_2 can be calculated by temperature difference, so the total energy recovered in summer is Q_1+Q_2.

2) Winter condition

The RIEC can act as a sensible heat exchanger in winter and the energy saving can be calculated by temperature difference.

3) Annual energy and electricity savings

The operation schedule for the RIEC system is 7:00 to 21:00 from 1st May to 31st October in summer (2576 hours in total) and from 1st, December to 28th, February in winter (1260 hours in total). Suppose the COP of the chilled water unit is 4.5. The energy saving (kW) can be calculated by annual heat recovery divided *COP*. As electricity is needed to drive the water pumps and fans of the RIEC unit, the net energy saving should excluded electricity consumption.

3.1.2. Rotating heat recovery wheel system

There're two kinds of rotating heat recovery wheels, which are sensible heat recovery wheel and enthalpy heat recovery wheel. The sensible heat recovery wheel can only recovery sensible heat; while enthalpy heat recovery wheel contains moisture absorption material or other regenerative hygroscopic materials on the surface of the aluminium foil, so it can deal with both sensible and latent heat.

The ROTOR rotating heat recovery wheel is chosen as the device with a sensible efficiency of 70%, enthalpy efficiency of 75% and energy consumption of 1.5 kW.

3.2. Economic analysis

The economic effect can be evaluated by payback period, which is the initial investment (HK$) divided by the annual money saving (HK$/year). Usually, it is acceptable for a payback period less than 10 years in engineering application. The investment of the equipment is listed in Table 2.

Table 2 Investment of the equipment

Item	RIEC system	Enthalpy heat recovery wheel
One unit cost (HKD)	100,000	80,000
Installation charge(HKD)	200,00	200,00
Shipping charge (HKD)	10,000	10,000
Total cost (HKD)	230,000	190,000

4. Result and discussion

The air-conditioning system without any recovery device has been used as the basis of the comparison. Figure 2 shows the calculation results of the three A/C systems. From Figure 2 we can see that the RIEC system has the largest annual energy saving potential among all the systems, 45% higher than the enthalpy heat recovery wheel system, and six times higher than the sensible heat recovery wheel system. However, the RIEC is not the most energy efficient heat recovery system in winter because it can only recover sensible heat rather than the simultaneous heat and mass transfer in the enthalpy heat recovery wheel. Through calculation, HK$79232 can be saved by adopting the fresh air pre-cooling RIEC.

According to equation (15), the payback period of the RIEC system is 2.9 years while enthalpy heat recovery wheel is 3.5 years. As the payback period is less than 10 years, it's reasonable for adopting the RIEC in Hong Kong for providing an alternative heat recovery method for similar hot and humid areas.

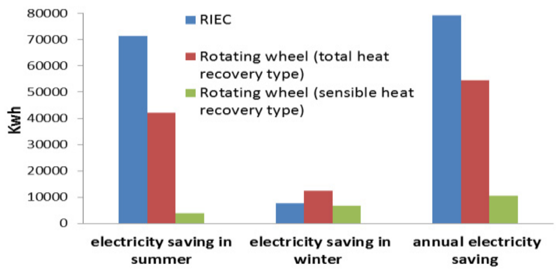

Figure 2 Energy saving potential of different system

5. Conclusion

This paper studied a case for applying RIEC technology to an all-fresh-air A/C system of a wet market in Hong Kong. The results show that the RIEC has the largest annual energy saving potential among the RIEC system and two kinds of rotating heat recovery wheel system, with a payback period of 2.9 years. Annually, HK$79232 can be saved by the fresh air pre-cooling RIEC system, which is 45% more than the enthalpy heat recovery wheel system, showing a great potential of application in Hong Kong.

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Biography

Yi CHEN, PhD student major in Building Service Engineering of Hong Kong Polytechnic University. The major research interest and field lies in the heat and mass transfer process in indirect evaporative cooling as well as the energy performance analysis.